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Vacuum ultraviolet spectrum of the neutral sulphur atom, S I

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SUMMARY

The strong S I lines in the vacuum ultraviolet region have been measured, and the values of some deep terms have been revised by use of the new measurements. The level $3s3p^5\,{}^1P_1$ was found, and the difference ${}^1D-{}^1S$ in $3s^23p^4$ accurately determined.

Introduction

S I has been examined in the vacuum ultraviolet region by Ruedy [1]. His identification of $3s^23p^4\,{}^1S_0$–$3s^23p^3({}^2P)4s\,{}^1P_1$ was later changed by Bowen [2] to the line at 1782 Å, and by use of the trend of the ${}^1S$ position through the higher members of the isoelectronic sequence from S I to Ti VII Edlén [3] confirmed this change. The forbidden transition $3s^23p^4\,{}^1D_2$–$3s^23p^4\,{}^1S_0$ is of astrophysical interest, and the present work was started primarily to get a good value of this difference.

Experimental arrangements

The sliding vacuum spark described in the author's paper on Si IV [4] was used. The inductance coil was made larger for the present purpose, and the spark produced S I with good intensity when 90 turns of the coil and a capacitance of 0.15 μF were used and the external spark gap was less than 0.5 mm or closed. Lines of S II were separated from those of S I by using about 30 turns of the induction coil and a 2 mm external spark gap, in which case the S I transitions were much weakened. The electrodes were made of beryllium, the lower one with a hole into which pure sulphur was fused and the upper one with a piece of carbon inserted to give reference lines (cf. [5], Fig. 1). The repetition frequency of the spark was regulated so that the sulphur should last for at least two hour's exposure.

A grazing-incidence vacuum spectrograph with a 1.5 m N.P.L. grating was used. The plate factor varies from 5.3 Å/mm at 1800 Å to 4.6 Å/mm at 1300 Å. The plates were coated with Ilford Q_2 or Kodak SWR emulsions.

Table 1. S I lines in the vacuum ultraviolet region.

I	$\lambda_{(obs)}$, Å		$\sigma_{(obs)}$, cm^{-1}	$\lambda_{(calc)}$, Å [a]	Combination
	This work	Ruedy			
7	1826.261	.25 (25)	54 756.69	.255	$3s^23p^4\,{}^3P_0-3s^23p^3(^4S)\,4s\,{}^3S_1$
7	1820.361	.37 (25)	54 934.16	.350	${}^3P_1-$ ${}^3S_1$
8	1807.341	.31 (25)	55 329.90	.336	${}^3P_2-$ ${}^3S_1$
4	1782.258	.25 (12)	56 108.60	${}^1S_0$	${}^1S_0-$ $(^2P)4s\,{}^1P_1$
2	1687.49	.54 (20)	59 259.6	${}^1P_1$	${}^1S_0-$ $3s3p^5\,{}^1P_1$
6	1666.691	.68 (25)	59 999.12	$3p^4\,{}^1D_2$	${}^1D_2-3s^23p^3(^2D)4s\,{}^1D_2$
4	1487.149	.12 (15)	67 242.76	.153	${}^3P_0-$ $(^2D)4s\,{}^3D_1$
1	1485.613	.61 (12)	67 312.28	.626	${}^3P_0-$ $(^4S)3d\,{}^5D_1$
4	1483.232	.24 (12)	67 420.34	.235	${}^3P_1-$ $(^2D)4s\,{}^3D_1$
5	1483.036	.05 (15)	67 429.25	.040	${}^3P_1-$ ${}^3D_2$
4	1481.680	.65 (15)	67 490.96	.745	${}^3P_1-$ $(^4S)3d\,{}^5D_0$
				.716	${}^3P_1-$ ${}^5D_1$
				.666	${}^3P_1-$ ${}^5D_2$
2	1474.569	.54 (6)	67 816.43	.583	${}^3P_2-$ $(^2D)4s\,{}^3D_1$
4	1474.390	.37 (12)	67 824.66	.391	${}^3P_2-$ ${}^3D_2$
6	1474.005	3.98 (15)	67 842.38	.007	${}^3P_2-$ ${}^3D_3$
5	1472.993	.97 (15)	67 888.99	3.082	${}^3P_2-$ $(^4S)\,3d\,{}^5D_1$
				3.033	${}^3P_2-$ ${}^5D_2$
				.985	${}^3P_2-$ ${}^5D_3$
4	1448.254	.20 (12)	69 048.66	${}^1P_1$	${}^1D_2-$ $(^2P)4s\,{}^1P_1$
2	1444.317	.27 (6)	69 236.88	${}^1D_2$	${}^3P_2-$ $(^2D)4s\,{}^1D_2$
3	1437.005	6.94 (12)	69 589.18	${}^3D_1$	${}^3P_0-$ $(^4S)3d\,{}^3D_1$
4	1433.328	.28 (15)	69 767.70	.346	${}^3P_1-$ ${}^3D_1$
				.310	${}^3P_1-$ ${}^3D_2$
3	1425.229	.10 (15)	70 164.16	${}^3D_2$	${}^3P_2-$ ${}^3D_{2,1}$
4	1425.065		70 172.24	${}^3D_3$	${}^3P_2-$ ${}^3D_3$
1	1412.899	.85 (12)	70 776.47	.899	${}^3P_0-$ $(^4S)5s\,{}^3S_1$
2	1409.368	.32 (12)	70 953.79	.361	${}^3P_1-$ ${}^3S_1$
2	1401.541	.50 (10)	71 350.04	.548	${}^3P_2-$ ${}^3S_1$
3	1396.147	.10 (15)	71 625.70	.139	${}^3P_1-$ $3s3p^5\,{}^3P_2$
2	1392.607	.59 (12)	71 807.77	.603	${}^3P_0-$ ${}^3P_1$
1	1389.160	.16 (5)	71 985.95	.167	${}^3P_1-$ ${}^3P_1$
3	1388.463	.39 (12)	72 022.08	.471	${}^3P_2-$ ${}^3P_2$
1	1385.524	.51 (12)	72 174.86	${}^3P_0$	${}^3P_1-$ ${}^3P_0$
2	1381.571	.55 (15)	72 381.37	.575	${}^3P_2-$ ${}^3P_1$
0	1326.635	.64 (9)	75 378.68	.649	${}^3P_0-3s^23p^3(^4S)4d\,{}^3D_1$
1	1323.521	.52 (10)	75 556.04	.530	${}^3P_1-$ ${}^3D_1$
				.521	${}^3P_1-$ ${}^3D_2$
2	1316.57	.59 (8)	75 954.9	.637	${}^3P_2-$ ${}^3D_1$
				.628	${}^3P_2-$ ${}^3D_2$
				.557	${}^3P_2-$ ${}^3D_3$
3	1305.885	.89 (9)	76 576.42	.887	${}^3P_0-$ $(^2P)4s\,{}^3P_1$
3	1303.114	.12 (7)	76 739.26	.111	${}^3P_1-$ ${}^3P_0$
3	1302.865	.86 (6)	76 753.92	.865	${}^3P_1-$ ${}^3P_1$
4	1302.344	.32 (9)	76 784.63	.342	${}^3P_1-$ ${}^3P_2$
3	1296.174	.18 (5)	77 150.14	.185	${}^3P_2-$ ${}^3P_1$
4	1295.661	.62 (6)	77 180.68	.667	${}^3P_2-$ ${}^3P_2$

[a] A level symbol in this column indicates that the level is determined from this line alone.

Wavelengths measured in the region 2000–1200 Å

Table 1 contains all the measured S I lines in the vacuum ultraviolet region. The wavelengths given in the second column are weighted means of measurements on three spectrograms relative to lines of C I, C II, O I, Si II (for references see [5], Table 1), Si III [5], Si IV [4], and Be II [6]. The uncertainty in the observed wavelengths is estimated to be not more than 0.01 Å. Lack of references makes the uncertainty of the value λ 1687.49 Å somewhat larger. Ruedy's values, followed by his intensity figures in parenthesis, are given in the third column. The agreement is on the whole quite good. There is a systematic difference of about 0.04 Å between $\lambda\lambda$ 1480 Å and 1380 Å. The lines at 1914 and 1900 Å and a number of faint lines listed by Ruedy have not been observed in this work. One of his strongest lines, λ 1204 Å, as well as some of the weaker ones, have now been experimentally classified as belonging to S II. The line λ 1425 Å has now been resolved into two components, while λ 1316 Å shows a complex structure that could not be resolved.

Revised term values

The level values that have been directly determined by use of the new measurements are collected in Table 2. They are estimated to be correct within the limits ± 0.3 cm^{-1}. The differences between the new values and those given in Atomic Energy Levels [7] range from -4.0 cm^{-1} to $+1.5$ cm^{-1}. All term values not included in Table 2, as well as the ionization limit given in Atomic Energy Levels, should be reduced by 1.10 cm^{-1}.

The term $3s3p^5\,{}^1P_1$ needs to be confirmed as it is based only on its combination with $3s^23p^4\,{}^1S_0$. The transition $3s^23p^4\,{}^1D_2$–$3s3p^5\,{}^1P_1$ is quite strong in the isoelectronic spectra Cl II, Ar III, K IV, Ca V, and Sc VI, as was pointed out by Edlén [3]. It is surprising, therefore, that no line corresponding to that transition can be found in S I. The level $3s^23p^4\,{}^1S_0$ is also based on only one transition, viz. $3s^23p^4\,{}^1S_0$–$3s^23p^3(^2P)4s\,{}^1P_1$ at 1782 Å. By investigating the long-wave region it is hoped to confirm $3s3p^5\,{}^1P$ through other combinations and thereby obtain the definite proof for $3s^23p^4\,{}^1S$.

Table 2. Revised S I levels.

Term symbol	E, cm^{-1}	ΔE	Term symbol	E, cm^{-1}	ΔE
$3s^23p^4\ {}^3P_2$	0.00	-395.56	$3s^23p^3(^4S)5s\ {}^3S_1$	71 349.68	
${}^3P_1$	395.56	-177.63	$3s3p^5\ {}^3P_2$	72 021.67	-359.50
${}^3P_0$	573.19		${}^3P_1$	72 381.17	-189.25
$3s^23p^4\ {}^1D_2$	9 237.76		${}^3P_0$	72 570.42	
$3s^23p^4\ {}^1S_0$	22 177.82		$3s^23p^3(^2P)4s\ {}^1P_1$	78 286.42	
$3s^23p^3(^2D)4s\ {}^1D_2$	69 236.88		$3s3p^5\ {}^1P_1$	81 437.4	
$3s^23p^3(^4S)3d\ {}^3D_3$	70 172.24	8.1			
${}^3D_2$	70 164.1	1.7			
${}^3D_1$	70 162.37				

The difference ^1D–^1S in $3s^23p^4$

According to the new level values the wave-number of $3s^23p^4\,{}^1D_2$–$3s^23p^4\,{}^1S_0$ is 12 940.0 cm^{-1}, corresponding to $\lambda_{\text{air}} = 7725.8$ Å as compared to 7724.4 Å obtained from the term values in Atomic Energy Levels. The uncertainty of the present value should not be more than 0.3 Å. Bowen [8] has observed a faint line at 7726.5 ± 0.3 Å on one spectrogram of a nebula and identified it with this transition. In a later paper [9], however, he appears to prefer the value calculated from Atomic Energy Levels.

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